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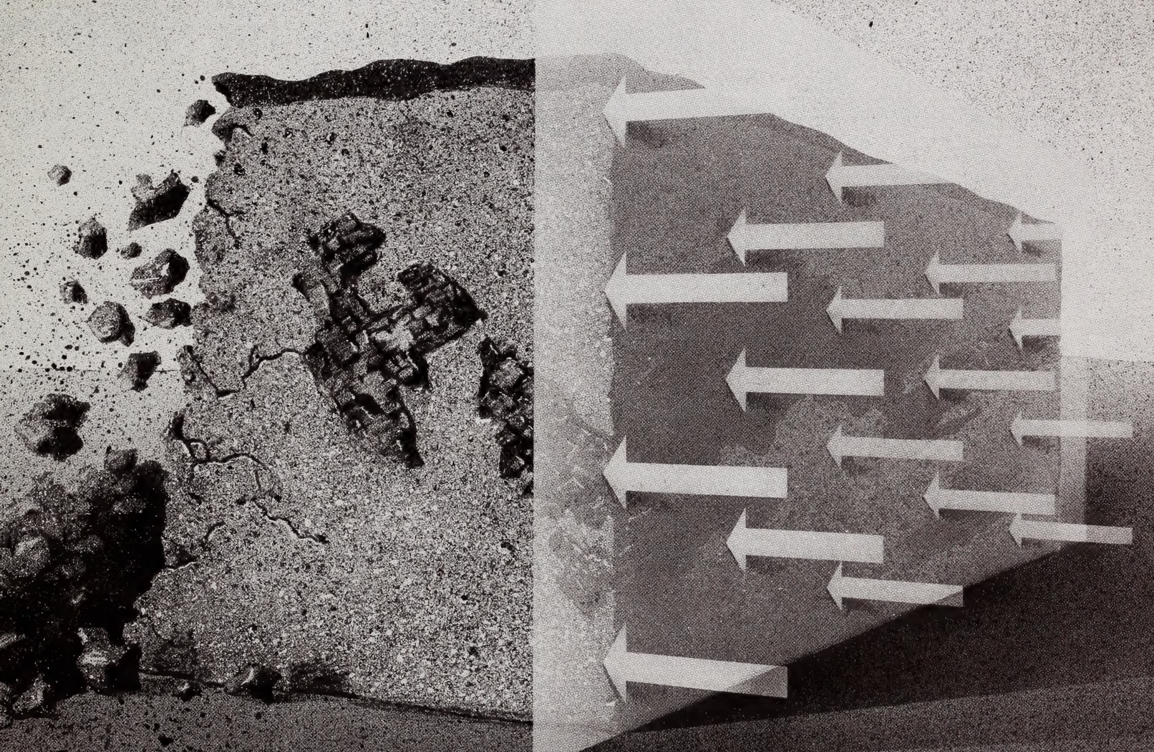
Geotechnical Studies of Overburden and Coal at Alberta Coal Mines

Projects supported in part
by the Alberta/Canada
Energy Resources
Research Fund



ALBERTA
OFFICE OF
COAL
RESEARCH &
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1990
Edmonton

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ENERGY
Research and Technology Branch

Pub. No. I/353

ISBN 0-86499-742-6

Foreword

Since 1976, numerous projects have been initiated in Alberta by industry and by academic research institutions which are aimed at better utilization of Alberta's energy resources.

These research, development and demonstration efforts were funded by the Alberta/Canada Energy Resources Research Fund (A/CERRF), which was established as a result of the 1974 agreement on oil prices between the federal government and the producing provinces.

Responsibility for applying and administering the fund rests with the A/CERRF Committee, made up of senior Alberta and federal government officials.

A/CERRF program priorities have focused on coal and conventional energy resources, as well as energy conservation and renewable energy. Program administration is provided by staff within the Research and Technology Branch of Alberta Energy.

In recognition of the importance of coal to Alberta's economy, the Alberta Office of Coal Research and Technology was established in 1984 within Alberta Energy and Natural Resources (now Alberta Energy). Its primary purpose is to encourage the development and application of new technologies related to Alberta coals. The Office provides funding contributions to research and development projects in industry, academic institutions and other research establishments and monitors their progress in an overall program of improving the production, transportation and marketability of Alberta coals.

In order to make research results available to industry and others who can use the information, highlights of studies are reported in a series of technology transfer booklets. For more information about other publications in the series, please refer to page 13.

Geotechnical Studies of Overburden and Coal at Alberta Coal Mines

Geotechnical investigations generally involve making predictions about the likely response of the Earth's surface to physical stresses caused by natural forces, or those initiated intentionally by man. Thus, the principles of solid mechanics, fluid mechanics and two-phase flow are applied in geotechnical studies.

These studies could be of a geophysical nature, in which small electrical, nuclear or mechanical stresses are applied at certain locations on the Earth's surface, and the response is recorded by sensitive instruments. Such studies have been funded by the Alberta/Canada Energy Resources Research Fund (A/CERRF), and they will be described in a subsequent publication.

Other geotechnical studies involve making predictions about the stress-strain relationships that occur when large masses of earth are excavated, or measuring localized effects when heavy equipment passes by. Therefore, these kinds of studies can apply to areas as small as a few square metres or as large as several square kilometres.

Groundwater flow is an important factor when undertaking geophysical work. When rock masses are subjected to mining operations, groundwater flow will affect pore pressures and effective stress relationships of the material.

From 1981 to 1989, several geotechnical studies directly related to coal mining in Alberta were funded by A/CERRF. They are described here. In particular, a demonstration involving intentional anchoring of a footwall in an open-pit coal mine has become one of the more successful projects funded by A/CERRF. Its success can be measured in terms of financial benefits derived from an investment in research, and it also represents a technology that can be employed in most Alberta coal-extraction operations.

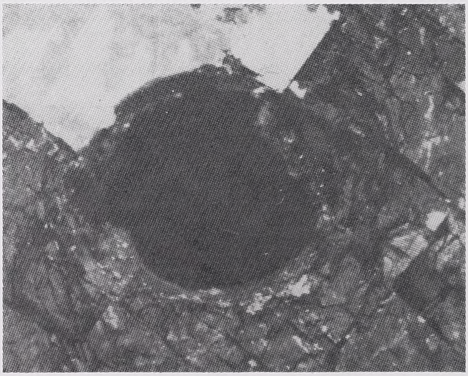
Support Design for Underground Cavities in Weak Rock

Unlike metallic ore deposits, coal seams are often surrounded by weak rock formations. This lack of strength in the surrounding rock creates challenges for the design of underground mines. While the need for safety is paramount, mine engineers must still design the least expensive support system to prevent collapse of mine tunnels and work places.

It is extremely difficult to design support systems based on analytical methods because the geology of a particular mine site will vary across the site and from one section of a coal seam to another. Consequently, the designs for most support systems are based on experience and detailed observations of particular mines.

In a three-year study conducted at the University of Alberta, an attempt was made to develop a more rational method for designing underground support systems. Cylindrical holes were drilled into blocks of Highvale coal to simulate underground tunnels, and a special laboratory test apparatus was used to apply pressure to the blocks. Changes in the size and shape of the holes and surrounding coal were measured.

It was found that the size of the holes changed with time and pressure, and that the rate at which these changes occurred could be related to the likelihood of failure of the specimen. The investigators recommended that the rate of change in tunnel dimensions in real mines be monitored because the information could be used to assist in designing appropriate support structures.



Rock sample with opening after stress/creep simulation test

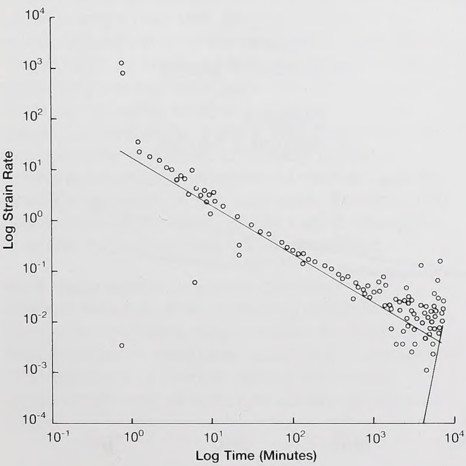
Creep Characteristics of Coal

When solid materials, such as coal, are subjected to mechanical stress, they can exhibit a property known as creep. This refers to a slow, time-dependent change in the physical dimensions of the material and it can result in mechanical failure. This is particularly relevant to coal pillars left in underground mines to support the working area. Creep, though difficult to assess, is an important consideration in mine safety.

In a study conducted at the University of Alberta, the time-dependent strain and creep characteristics of subbituminous coal from the Highvale mine were measured. It was found that under constant applied pressure, creep decelerated initially for all samples. After several hours, or several thousand hours in the case of some specimens, creep began to accelerate. This led to eventual failure of the samples.

A mathematical model was developed which was able to express adequately the relationship between strain rate and time for coal, and a computer program called CPACK was written to analyse the experimental results. An attempt to find the stress dependence of the creep rate for a model coal pillar, however, was unsuccessful because the deformation properties of coal vary from seam to seam and within seams.

Logarithmic plot of strain rate (micro-strain/min.) vs time (min.) for subbituminous coal



(Source: Movement Before Failure of a Model Coal Pillar, Cruden, D.M. and K.W.Y. Leung, University of Alberta, 1984)

Time-Dependent Behaviour of Coal Measure Rocks

In planning underground coal mines in western Canada, it is important to be aware of the likely behaviour of soft rocks that commonly surround coal seams. For example, the roofs of mine shafts can sag, floors can heave and pillars can deform appreciably. Many of these changes are not predicted accurately by current methods.

In this project, initiated in 1986, computer simulations were developed to predict the creep behaviour of soft rocks, coal and potash using data from simple, rapid testing of cores.

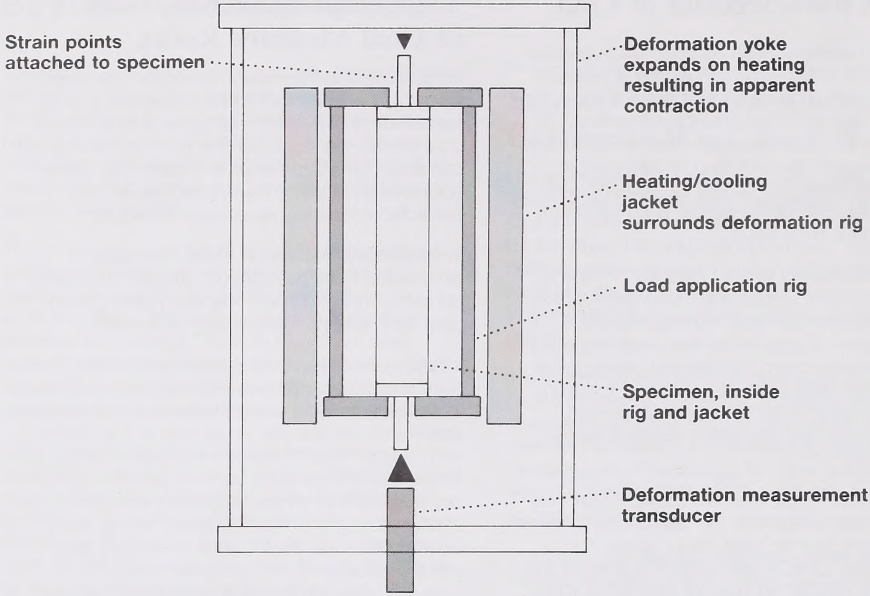
Initially, a theoretical examination was made of the suitability of using an activation spectrum approach to describe time-dependent behaviour. The activation-spectrum concept was developed in the 1940s and '50s to describe transient creep in metals, and it was found to be applicable to describe creep in any material that shows significant microstructural change during the creep process. In this study, extensions to the theory were developed from previous studies of the creep behaviour of concrete. Also, an interactive computer program was developed, which allowed examination of the creep process and determination of changes in materials under load as creep proceeded.

The suitability of the model was examined in two ways. First, an attempt was made using data obtained from an extensive literature review to calculate material parameters that could be used in the model. It was found, however, that few experiments yielded useful data. Thus, an experimental program was initiated to examine the creep behaviour of mining materials. Because the scope of the program was limited, only one material, potash, was used for examination. This was done because the creep behaviour of potash is qualitatively similar to other mining materials, such as coal and soft rock.

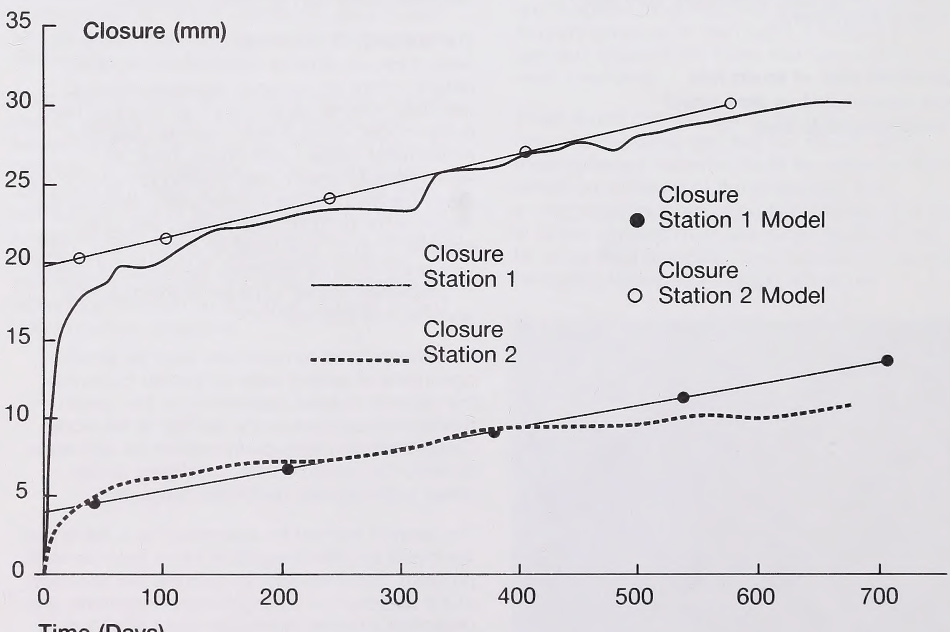
Incremental load-temperature tests on small specimens of potash were performed to provide the relevant material parameters for the spectrum model and substantiate the viability of the model. Creep tests also were performed on full-size cores to relate the creep of small specimens to the creep tests normally performed on cores.

The second method for examining the suitability of the model involved integration into a finite element program. This was done to examine the accuracy of the approach to solving practical problems, and determine whether the model would give more realistic and accurate results than did current constitutive models.

Schematic of Creep-Testing Apparatus



Experimental and PCCREEP Modelled Data of Rock Mechanics Room in a Potash Mine



(Source: Modelling and Prediction of Time-Dependent Behaviour in Engineering Materials, Day, R.L. and R.J. Beddoes, University of Calgary, 1990)

Results from this study indicated that the spectrum approach, when compared to the power law, produced a significantly more accurate prediction of material response when changes in stress occurred. The spectrum model also accounted naturally for changes in material behaviour when the temperature changed.

The spectrum model was easily integrated into a finite element program, and was found to be "user-friendly." Persons wishing to obtain information about the availability of PCCREEP software and instruction manuals should contact the University of Calgary directly.

A full-scale, finite-element analysis for closure of a mine drift in a New Brunswick potash mine was performed. Data obtained from field measurements were compared to those of the simulated behaviour. Although relatively unrefined methods were used to determine relevant rate parameters from laboratory data, the spectrum approach produced accurate results for the magnitude of the transient component of closure. The steady-state component of creep was also included in the model and gave good results.

It was concluded that the spectrum approach for accurate prediction of time-dependent deformation in mining applications shows promise as a practical and realistic method of analysis.

Ground Movements in Coal Mines

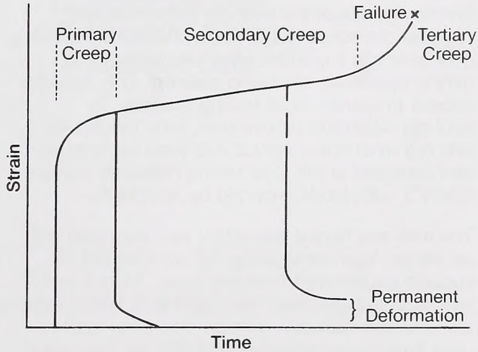
When coal seams or the rock that surrounds them undergo any movement, people working in the vicinity are exposed to the hazards of falling debris. Therefore, if such movements could be predicted, this would provide mine planners with improved methods for safely removing coal from surface mines. Consequently, a study was undertaken at the University of Alberta to develop predictive methods based on mathematical models used for landslide research. In this approach, the time- and deformation-dependency of the loss of strength of coal and rock when they fail was modelled.

Multi-stage creep tests were carried out on subbituminous coal from the Highvale Mine. Computer programs were modified to obtain the best fit between computer output and observations. This resulted in a formula relating rock mass displacement rate of a rupture surface to elapsed time.

To test the value of the new formula, it and three others were used to determine which would provide the best fit to records of a pit wall failure at an Alberta coal mine. It was found that mathematical methods which assumed that a condition of accelerating creep occurred in only two stages were not reliable in predicting the time to failure of the wall. When three stages were assumed, however, it was possible to predict the time of the critical slide velocity. This refers to the period when personnel and equipment should be evacuated from the pit. While the study resulted in a model capable of being used less widely than was desired when the investigation was begun, it did represent a step forward in understanding and modelling ground movements.

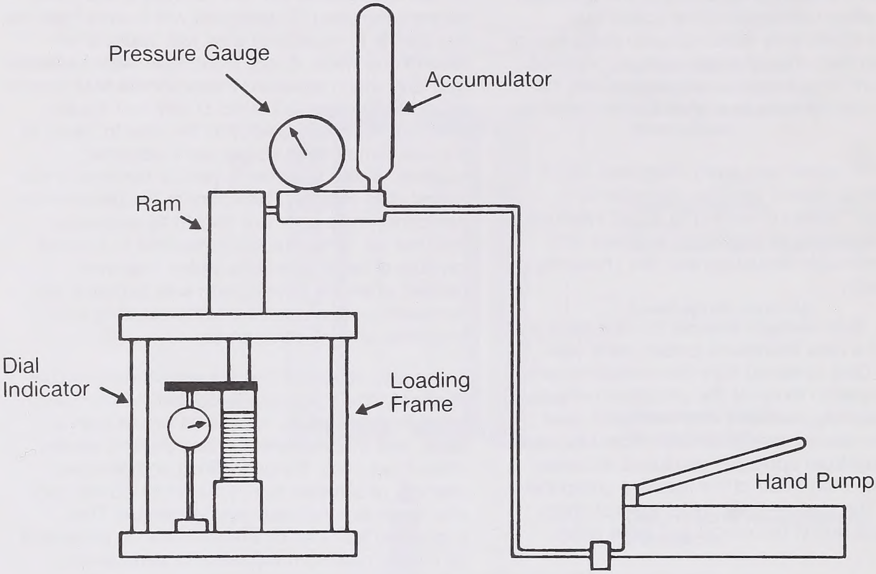
It was also observed that the subbituminous coal studied in this investigation lost half its short-term strength in five hours, two-thirds in less than a week, and three-quarters in less than 10 weeks under load. Also, the unconfined compressive strength of samples was reduced by 50 per cent after approximately one year in storage. This suggested that loss of strength may be prevented by sealing coal from exposure to atmospheric conditions. For example, Shotcrete spraying on exposed coal in permanent openings might be useful in this regard.

The relative magnitude of creep stages is shown in this strain diagram of subbituminous coal



(Source: Models for Monitoring Ground Movement in Coal Mines, Cruden, D.M. and S. Masoumzadeh, University of Alberta, 1986)

Creep Test Apparatus



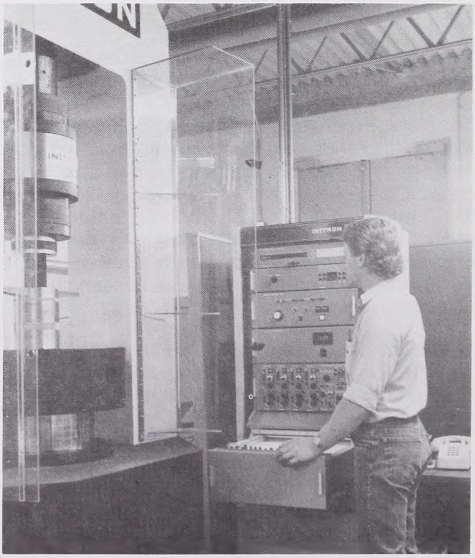
(Source: Models for Monitoring Ground Movement in Coal Mines, Cruden, D.M. and S. Masoumzadeh, University of Alberta, 1986)

Geotechnical Properties of Overburden

Knowledge about the strength properties and physical characteristics of rocks and soil surrounding coal seams is important when coal mines and mining operations are being planned. This requires access to geotechnical testing facilities. To accommodate this requirement, rock mechanics and soil mechanics laboratories were established and equipped at the Coal Mining Research Company (CMRC), with funds provided by A/CERRF.

The rock mechanics laboratory was equipped with an Instron load frame and a full complement of support equipment for testing cores, blocks and recompacted samples. The load frame, which can be operated manually or under computer control, uses detachable load cells of 4 500 kN (one million lb.) and 450 kN (100 000 lb.). Each cell has a rated precision of one per cent.

The soil mechanics laboratory established at CMRC was equipped with several instruments. A 50 kN triaxial test apparatus was obtained, which could be used to determine the strength of materials at various confining loads, as well as measuring the following: the volume change occurring in a specimen during testing; the permeability of soil; the residual strength of materials after peak load has been reached; and the rate of pore pressure dissipation. Equipment was also obtained to measure unconfined compression, shear, consolidation and Atterberg limits.



An Instron compression/tension load frame was used at the Coal Mining Research Company for uniaxial and triaxial rock testing.

Triaxial Test Development

The triaxial test apparatus obtained by CMRC comprised a 50 kN load frame, a triaxial and permeability control panel, and a triaxial cell. This device could be used to determine the strength of a material at various confining loads, as well as the amount of volume change that occurred in a specimen during testing, the permeability of a soil type, the residual strength of a material after peak load has been reached, and the rate of pore pressure dissipation.

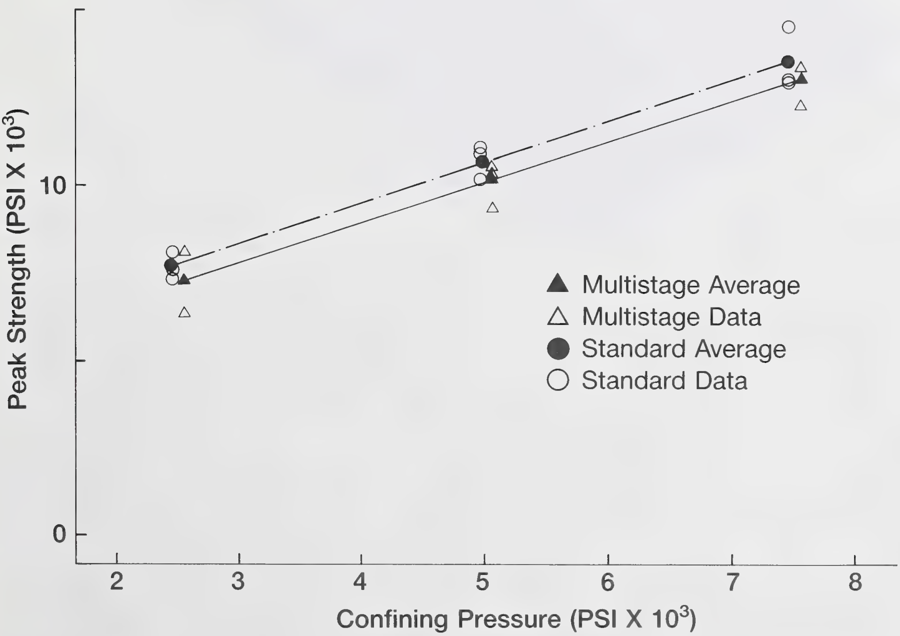
This equipment was used to develop a cost-effective, multi-stage method for obtaining information about the strength properties of rock and coal.

The test method provides three or more times as much information from a single specimen as the standard method of triaxial testing, and at the same cost.

Two subbituminous coals (from the Vesta and Highvale mines), as well as mudstone, sandstone and concrete were tested with the new, automated method, and the results were verified by testing with the conventional triaxial test method.

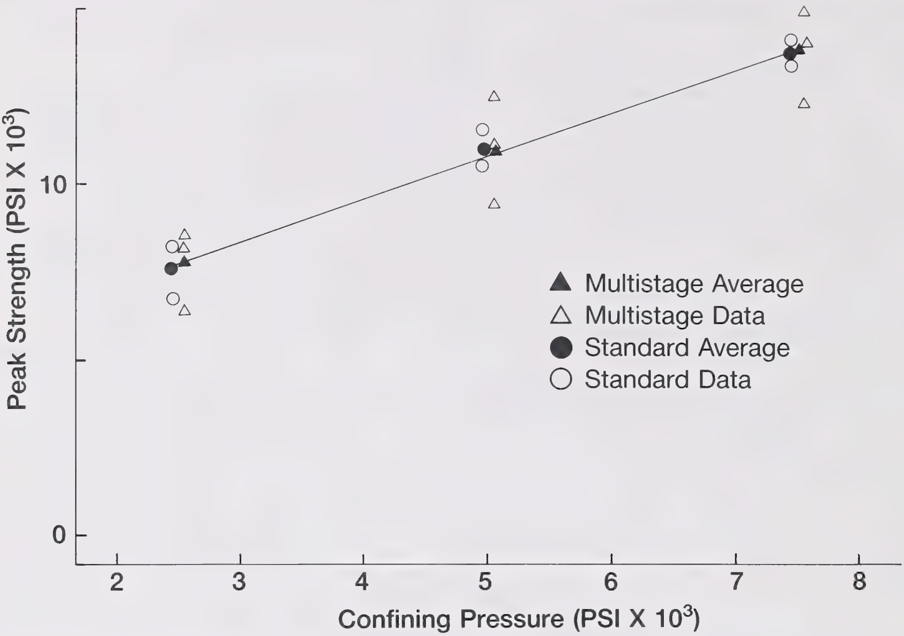
It was demonstrated that multi-stage triaxial test results could be replicated, and experimental error was reduced significantly over conventional triaxial testing on brittle materials. Also, samples could be tested in less time.

Comparison of Peak Strengths for Highvale Coal



(Source: Multistage Triaxial Test Development, Hollingshead, B.G. and A.M. Willott, Coal Mining Research Company, 1987)

Comparison of Peak Strengths for Vesta Coal



(Source: Multistage Triaxial Test Development, Hollingshead, B.G. and A.M. Willott, Coal Mining Research Company, 1987)

Deformation and Progressive Failure of Open-Pit Highwalls

When a highwall fails in an open-pit mine, the falling debris can injure workers, damage mining equipment and cause costly delays. Some of these difficulties can be avoided or minimized if improved methods of predicting highwall failure can be developed.

In this project, begun in 1986, highwall deformation was studied as mining progressed in an open pit at the Highvale Mine, and a failure of the highwall was analysed.

In plains mines in particular, the soft bedrock is broken into small blocks by fractures and joint systems. Excavations in this material cause significant deformations that stretch the bedrock. This opens the fissures and spreads the blocks of rock farther apart. The result is a loosened rock mass that is weakest near the highwall. The relationship between loosening caused by excavation and subsequent strength reduction is called the "loosening mechanism." It was the focus of this project.

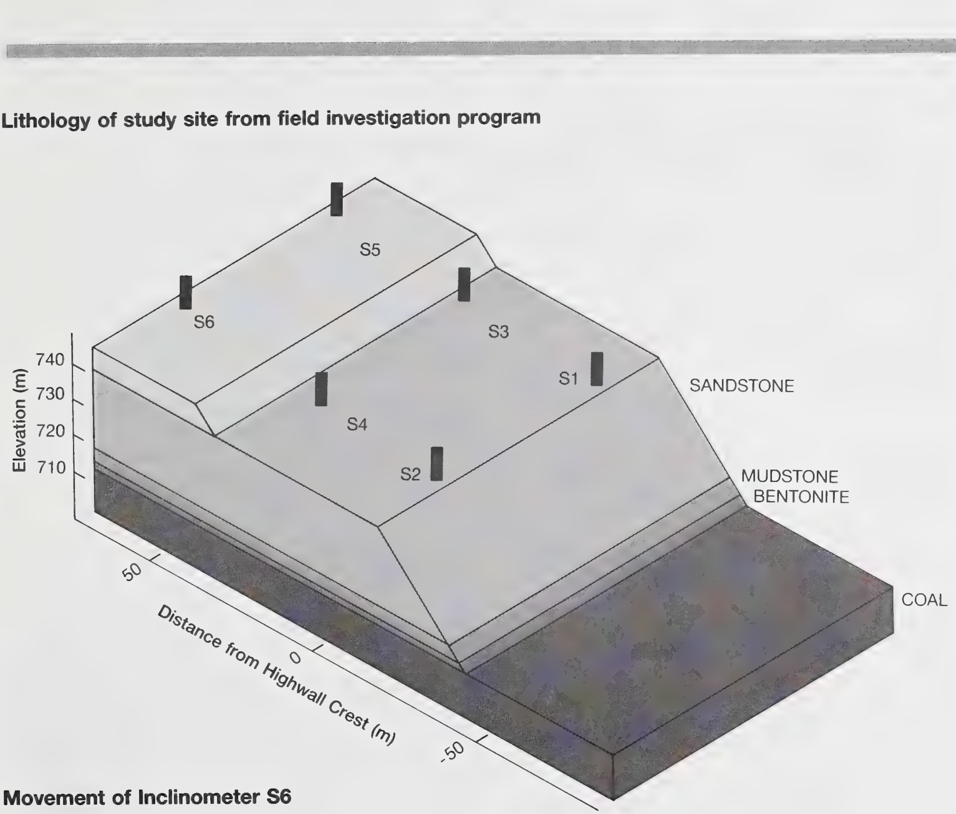
At the mine site, horizontal and vertical surface deformation was measured using survey techniques that employed a series of inclinometers. Piezometers were used to measure variations in the water table, and the strata comprising the highwall were analysed for stress-strain properties.

During the monitoring phase of the project, significant movement was detected in several shear zones. The instrumentation was able to detect the onset of highwall movement, the extent of movement behind the highwall crest, and variations in the deformation mechanisms over a short distance.

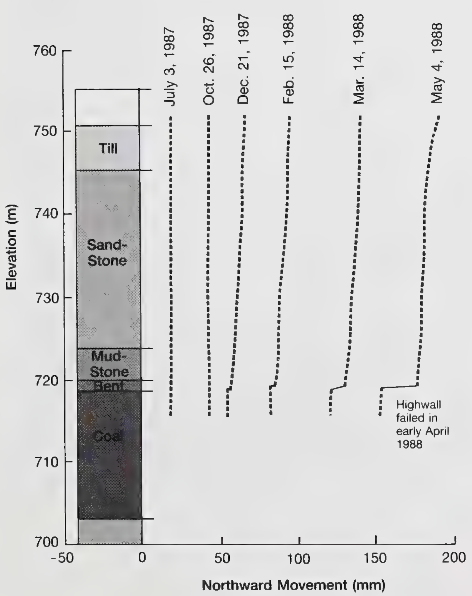
The degree of loosening was expressed as a "loosening strain," which was obtained by differentiating the horizontal deformations caused by excavation. For example, where the loosening strain approached zero behind the highwall face, the bedrock was considered to be unloosened. However, the loosening strain reached a maximum in the fully loosened state at the highwall face.

The undisturbed rock strength was approximated from laboratory testing, taking into account the effect of discontinuities. The fully loosened strength could only be calculated from analyses of highwalls that had failed.

Lithology of study site from field investigation program



Movement of Inclinometer S6



(Source: Failure of Mine Highwall in Soft Sedimentary Rock, Morgenstern, N.R. and C.A. Small, University of Alberta, 1990.)

The discovery of a connection between extension strain and strength reduction provides a basis for the development of more effective analytical and monitoring strategies.

Several conclusions were drawn from the study. The magnitude of rebound movement could be monitored effectively by a combination of inclinometers and surveying. This mixture of measuring techniques was used to find deformations at any point in the overburden. These deformations were then converted to lateral strains that were a measure of how much the overburden rock and soil "stretched" or loosened from their original state.

It was also found that strains of approximately 0.7 per cent could be measured at the highwall as it rebounded into the pit. Strains at the highwall were found to vary with time and stratigraphy.

Also, lateral straining caused previously impervious layers to open and allow water to flow through. This altered the groundwater regime from a combination of perched water tables and confined aquifers to a freely draining, pervious formation underdrained by the coal. In addition to changing the flow patterns, the lateral strains also caused a proportionate reduction in the strength of the rock mass. With higher strains, the overburden strata became weaker.

It was suggested that two mechanisms helped to reduce the strength of the rock mass as it stretched into the pit: progressive loosening and progressive softening. The former mechanism developed as joints in the rock mass spread apart. This reduced the normal stresses along the joints and reduced their shear strength. In addition, the joint spreading exposed new surfaces to the flow of groundwater that resulted in a softening of the formation. Both mechanisms were described as "progressive" because they are dependent on the amount of lateral straining.

These considerations led to an explanation of the highwall failure. It was postulated that excavation rebound resulted in a progressive loosening and softening of the sandstone and mudstone that decreased their strengths to unstable levels. When this was combined with unfavourable joint conditions in the sandstone, the highwall failed. Secondary contributors to the failure were the available water pressures and a layer of pre-sheared bentonite that acted as the basal slip plane.

It is believed that these findings should greatly assist highwall designers in understanding the processes at work in any open-pit mining operation in Alberta.

Footwall Anchoring

Coal mining in the mountain region of Alberta often involves extraction from seams that were thrust into nearly vertical positions when the mountains were formed. When open-pit mining is used on these seams, it exposes a steeply dipping footwall of rock below the coal. This wall of rock is not sufficiently strong to stand by itself; hence, special measures are required to ensure the safety of miners working below it.

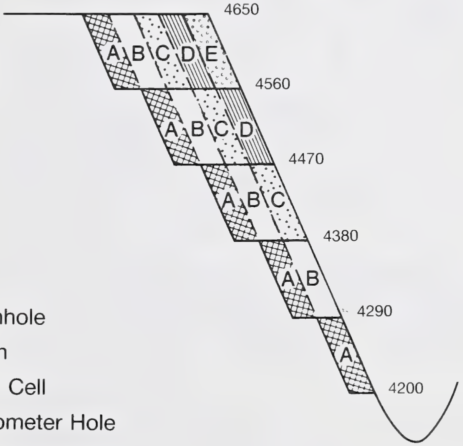
Occasionally, instability in a footwall requires emergency placement of steel anchors in the rock face to keep it in place. In an experiment carried out at the No. 9 Mine of Smoky River Coal Limited near Grande Cache, pattern footwall anchoring was purposely planned and executed as a means of reducing the amount of waste material that had to be removed from the pit.

Comparison of Anchoring and Benching Alternatives

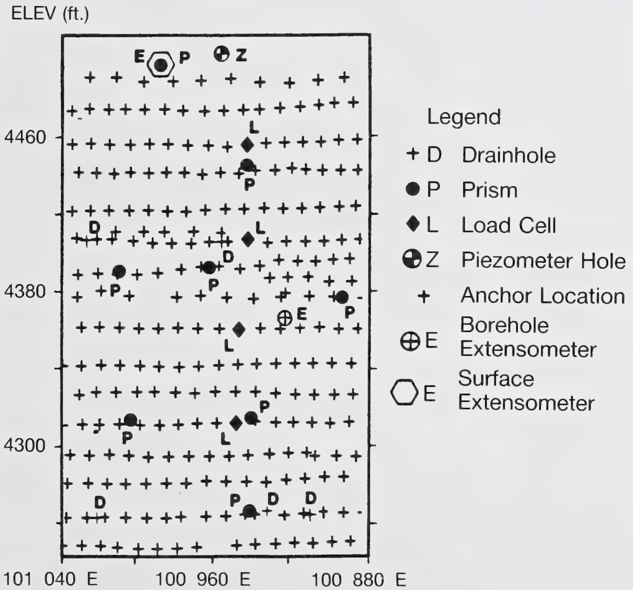
Case	Number of Benches Anchored	Total Reduction in Waste Removal (%)	Incremental Reduction in Waste Removal (%)
A	1	33.3	33.3
B	2	60.0	26.7
C	3	80.0	20.0
D	4	93.3	13.3
E	5	100.0	6.7

(Source: Upper East Limb Open Pit Rock Anchoring and Slope Monitoring Project: Final Report, Smoky River Coal Limited and Piteau Associates Engineering Ltd, 1987)

Benches (numbers refer to elevation in feet)



Face-on Plan for an Area of Footwall Slope Showing Distribution of Remedial Measures and Instrumentation



(Source: Assessment of Instrumentation Systems for a Footwall Slope at Smoky River Coal, Martin, D.C. and P. Sheehan, Smoky River Coal Limited/Piteau Associates Engineering Ltd, 1988)

The pit was eventually developed to a length of 457 m (1 500 ft.) and a height of 152 m (500 ft.), with a footwall of corresponding dimensions at an angle of approximately 65° to the horizontal. Normally in a situation like this, the footwall is cut away in benches at 14-m (45-ft.) intervals, but this involves removal of considerable quantities of rock at a substantial cost to the mining company. In this particular case, it was decided that installation of rock anchors along the footwall, as the pit developed, would be less expensive than benching. The footwall, therefore, was benched for approximately half the pit height and anchored for the remaining 75 m (250 ft.).

Subsequently, 1 764 tensioned rock anchors measuring 6 or 9 m (20 or 30 ft.) in length, along with 600 mechanical rock bolts, wire mesh and drainholes, were placed along the footwall as the pit developed. Also, an extensive system of monitoring equipment was installed, and measures were taken to assess the overall stability of the slope and provide some warning if movement or failures occurred along the footwall. This included the use of 47 survey prisms, 9 surface extensometers, 2 bore hole extensometers, 23 load cells, 2 piezometers, and visual inspections.

Although significant movement of the footwall was detected during the last month of the two-year mining activity, all the coal was successfully extracted from the pit. Approximately two months after mining was completed, the footwall failed.

Anchoring was accomplished at a cost of approximately $1.1 million, which is 62 per cent of the cost of benching. Without anchoring, recovery of the coal would have been marginally economic.

In assessing the value of the various monitoring instruments, it was concluded that the survey prisms were the most effective, but the other instruments were essential for accurate assessment of slope behaviour and the effectiveness of remedial measures.

While the mining geometry, engineering geology and slope behaviour were unique to this location, the monitoring and slope assessment techniques used in this project may be applied to similar types of mining situations elsewhere.

Mining Technical Committee

In recent years, several research organizations, companies and funding agencies in Alberta have been involved in geomechanical studies of Alberta's resources, including coal, but these investigations have been carried out independently of each other. For instance, the Alberta Office of Coal Research and Technology has supported 14 coal-mining research projects since 1985, and in 1990 another was under way in the Western Canadian Low-Sulphur Coal to Ontario Program. In May 1988, the Mining Technical Committee was formed to co-ordinate research and development funding among federal and provincial governments and private organizations in the area of coal production technology.

The technical committee comprises representatives of coal producers, research and development agencies, and the Alberta and federal governments.

The committee identified the following priority areas for investigation:

- mining costs;
- optimal recovery of resources; and
- product quality.

The committee participated in one coal-mining research project supported by the Office and is co-ordinating mining technology components of research associated with reducing the delivered cost of western Canadian coal in Ontario.

Further Reading

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More information about support design for underground cavities in weak rock, and deformation and progressive failure of open-pit highwalls, is available from:

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Pub. No. I/353
ISBN 0-86499-742-6